STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

A preliminary report on

MEASURING PAVEMENT ROUGHNESS FROM PROFILOGRAMS

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State of California
Department of Public Works
Division of Highways

MATERIALS AND RESEARCH DEPARTMENT

March 8, 1957

Mr. J. W. Trask
Assistant State Highway Engineer
Division of Highways
Sacramento, California

Dear Sir:

Submitted for your consideration is:

A preliminary report on

MEASURING PAVEMENT ROUGHNESS FROM

PROFILOGRAMS

Tests made by	Technical Section
Under general direction of. .	Bailey Tremper
Report prepared by.	D. L. Spellman

Very truly yours

F. N. Hveem

F. N. Hveem
Materials and Research
Engineer

MEASURING PAVEMENT ROUGHNESS FROM PROFILOGRAMS

Introduction

During the spring and summer of 1956, profilograms of selected pavements in nine districts were recorded with the new truck-mounted profilograph. These pavements were selected by the districts in response to a request for examples of "smooth" and "rough riding" pavements, both portland cement concrete and bituminous types. Of the profiles made, 30 miles were of portland cement concrete pavement representing 17 sections of road, and 32 miles were of bituminous type pavement representing 17 sections of road. Some sections were two-lane and others four-lane and since profiles were nearly always made in the two outer lanes, the lengths given above are only about one-half the total profiles obtained. All profiles represent the outer wheel track, about 30 inches from the edge of the pavement, recorded in the direction of traffic. From this group, 15 sections of portland cement concrete pavement and 11 sections of bituminous pavement were selected for study.

At the time the profiles were made, the operators recorded their personal observations as to relative roughness when driving over the roadway in a car. Disagreement in terms of personal impressions was found with very few of the district ratings. Such disagreement however, was only to be expected since the profilograph operators were making comparisons on a state-wide basis, while the districts were presumably comparing roads within their own areas. It is believed that the observations made by the Headquarters profilograph operators should be more consistent and for this reason they are used in the discussion that follows.

The classification as to riding comfort must necessarily be broad because in addition to the factor of personal reactions, speed and type of vehicle are other prominent variables. Nevertheless, among the pavements selected, examples were found that could be classified as distinctly either rough or smooth without much likelihood of disagreement. In the intermediate zone it is more likely that there would be some difference of opinion as to which pavements are smoother than others.

Methods of Profile Analysis Attempted

Profilograms show only vertical deviations of the pavement in one wheel track and are not necessarily in all cases a complete guide to "riding quality." Other factors affecting riding comfort are differences in elevation of both wheel tracks at a specific instant, wheel base, weight of car and its suspension system, tire pressure and speed of the vehicle.

Most profiles of old roads exhibit ups and downs; for convenience we propose to call these small vertical curves "scallops." These scallops assume some uniformity on curled pavements. The measurement of the areas inside these scallops with respect to some fixed datum, was attempted but the process was tedious and considerable variation occurred when attempting to retrace the curve with a planimeter. Smooth pavements have scallops which are too small for practical measurement. No results of this type are reported. Analysis on the basis of the size of vertical deviation was tried but it soon became apparent that such results could only be reported in very general terms. Measurement of the angles which one side of the scallop made with the horizontal was also made but on any one profile nearly all angles can be found. Peak-to-peak distance between "bumps" was also measured but this method did not give a clear picture of roughness either. Some of the data obtained from these various types of analyses is shown in Table 1. Similar data obtained from profiles of bituminous pavements are shown in Table 2.

Measuring Pavement Roughness from Profilograms

Recommended Procedure with Information at Hand

To speed up the evaluation and make use of the fact that rough roads showed scallops having ordinates over 3/8-inch, it was decided to try evaluating roads on the basis of vertical deviations only and "blank out" those portions of the profile showing only minor inequalities which apparently cause little discomfort to the passengers. A "blanking" band of 0.2 inch was arbitrarily selected and counts of the portions of the scallops exceeding that amount were made on several profiles by selecting one mile sections that were typical of the job.

It was found that a minimum of one mile of profile was needed to obtain a reasonably representative section of road. Even then some profiles exhibit wide difference in appearance from one end to the other and cannot well be represented as "average." This is one distinct advantage of the profile in that such varying areas can readily be seen and located on the road. The entire profile could be used in an analysis but of course this would lengthen the time required. The counts obtained varied from 2 inches to over 90 inches per mile. To avoid confusion with present established usage, the term "inches per mile" in excess of 0.2 inch will be given another name, "Profile Index (0.2")", leaving room for other terms which may correlate better with "Riding Quality." A Profile

Index (0.2") of 2 inches to 10 inches on a portland cement concrete pavement appears to be typical of new pavements and old ones in good condition. Counts of 40 or over would be considered rough. Examples of profiles of portland cement concrete pavements and their Profile Indexes are shown in Figure 1.

For bituminous roads, classification is a little more difficult because of surface texture and the fact that much discomfort in riding is due to side sway caused by difference in elevation of each wheel track at a particular instant. This condition is not so often found on portland cement concrete pavements. For these reasons some bituminous type roads are reported as rough but the type of roughness is not prominently shown in the profiles. Figure 2 shows typical profiles and Profile Indexes of bituminous pavements.

Scallops on the profiles that have a long distance (40 feet or more) from peak-to-peak are usually rounded and impart a smoother motion to the rider than do shorter dips (15 to 20 feet). These long waves give comparatively low counts because they occur less frequently per mile than do the shorter ones. Profiles Nos. 3 and 4 in Figure 1 illustrate this point. In the case of Profile No. 3, the scallops are about 25 to 35 feet long and occur about 175 times per mile while those in Profile No. 4 are about 15 feet long and occur some 350 times per mile. Profiles of bituminous roads exhibit this type of long undulation also, but in addition, they may have many smaller bumps due to cracking.

Other methods yet to be devised may better describe roughness. It appears however, that some compromise must be made to facilitate speed in evaluating roughness. Faulting up to 0.2 inch is presently disregarded in the Profile Index (0.2"). While sometimes annoying, the vibration caused by these minor faults do not create accelerations on the body large enough to produce discomfort to the passengers but the driver may receive shocks through the steering system. Discomfort to the driver due to faulting is not rated as severely by the Profile Index as is discomfort due to other types of distortion. The "roughometer" measures faults of all magnitudes but large long bumps and those occurring at culverts produce only slight increases in count which are believed to be too low in proportion to their contribution to riding discomfort. On relatively smooth roads it is these isolated rough spots which "throw" the passengers, especially in the rear seats. Curled pavements impart a movement that tends to be more severe to rear seat passengers than to front seat passengers at certain speeds. Also the effect varies markedly with length of vehicle wheel base.

Other Comments

A recent development in evaluating profiles using the "Fourier Series" has been made in the midwest. The general method is to break down the curve into "harmonics" according to amplitude and frequency. More information on this type of analysis is being secured but it is believed that such analysis can be applied only to curves that are cyclic, that is, have repeated scallops of the same shape and the analysis is quite involved. According to the information available now, a digital computer is used to evaluate the data.

An attempt is being made to correlate counts made from the profilograms with roughometer results by blanking out 0.1 inch and 0.3 inch in the profiles in addition to the 0.2 inch. The correlation is not too good. It should be remembered that the roughometer counts are taken in the left wheel track while the profilograms are normally made in the right wheel track. On roads having large amounts of faulting and corner breaks, the roughness is greater in the right wheel track and this may cause some lack of correlation.

Another factor which may cause poor correlation between the roughometer and profilograph counts is the fact that within one large scallop there can be many small bumps which are recorded by the roughometer, but in the case of the profilogram it would be evaluated in a different manner. Also to be considered is the difference in speed between the roughometer car and the profilograph truck. Dynamic effects at the 25 miles per hour rate at which roughometer counts are made, undoubtedly exaggerate some bumps and attenuate others.

The state of Kentucky has made a study of riding quality by measuring accelerations produced on the human body while driving over a roadway in a car at 50 miles per hour.

Three accelerometers are fastened to a breastplate in such a way that accelerations can be measured simultaneously in three directions. The breastplate is worn by the passenger in the front seat. The output is amplified and recorded on film by a recording oscillograph. The traces obtained are then evaluated by measuring the angle on each side of the waves and since the time interval can be measured, the movement can be converted to units of acceleration. The process is speeded up by the use of a special protractor which converts the "angles" into "g"s directly.

By previous experimentation with a human in a chair that can be given known acceleration in a given direction, comfortable levels of accelerations have been arbitrarily established. By counting the number of times the "comfort level" has been exceeded per mile as calculated from the oscillograph trace, one road can be compared to another. The Materials and Research Department is presently engaged in a project using the approach described above. The data obtained may be of great value in determining the full significance of the profiles.

When applied to bituminous pavements, the Profile Index is less satisfactory because it takes no account of minor irregularities that produce rumble, or of movements due to side sway which tends to be prevalent in this type of pavement. Nevertheless roads having a Profile Index (0.2") of less than 10 are generally found to be smooth and those with an index in excess of 40 are generally considered rough.

The profilograph offers a great possibility as a control of new construction as clear cut, detailed profilograms can be secured with a hand-push model a few hours after the pavement is placed. This will permit the Resident Engineer to evaluate his pavement finish immediately and take any needed corrective steps during construction. Subsequent profiles taken by Headquarters Laboratory on selected roads will enable us to evaluate performance of various pavement types and bases under varying traffic and climatic conditions.

TABLE I

PROFILE ANALYSIS SUMMARY SHEET - PCC PAVEMENTS

County, Route & Section	Length Miles	Classification	Size of Vertical Deviations (Log Scale) 1/4 3/8 ½ 3/4 1	Peak to Peak Distance 10' 20' 30' 40'	Predominate Angle, Degree	Profile Index (0.2")
VI-Fre-4-A	2.1	Smooth			Low	0.2
V-S.B-2-F	1.1	Smooth			5-15	3.8
IV-Ala-69-Berk	1.0	Smooth			Low	5.2
VIII-SBd-26-D	2.0	Smooth				
XI-S.D-199-Cor	2.2	Smooth			10-15	2.6
V-Mon-56-I	1.2	Smooth			10-15	9.7
I-Hum-1-Ftna	0.3	Fair			30-45	19.0
I-Men-1-Uki	0.5	Fair			45	13.8
VIII-Riv-19-B	1.0	Fair				9.7
IV-Ala-69-E	1.5	Fair			45-60	16.4
XI-S.D-2-S.D	0.7	Fair			45-60	21.9
IV-SCl-2-C	2.2	Rough			45-60	58.5
III-Gle-7-A	4.5	Rough			50-70	64.1
VI-Tul-4-B	2.2	Rough			45-60	44.7
V-Mon-2-Sal	0.7	Rough			30-60	

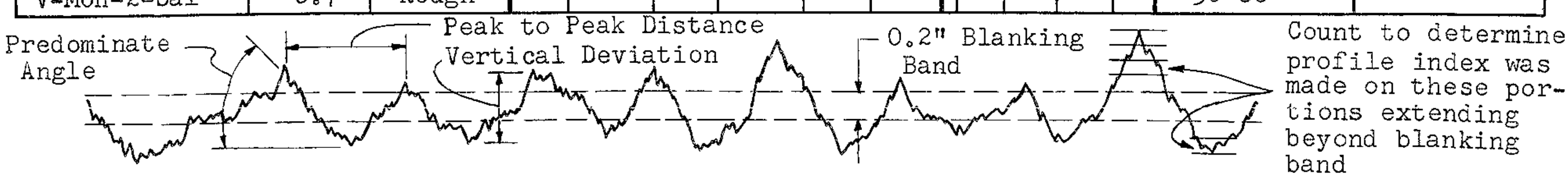


TABLE 2

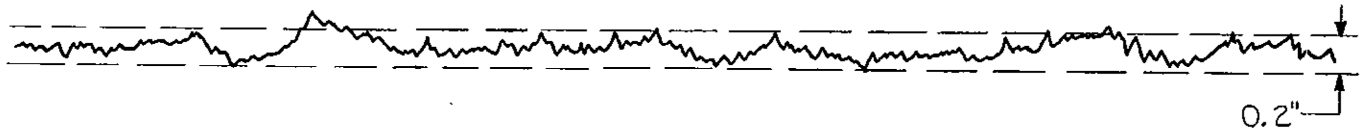
PROFILE ANALYSIS SUMMARY SHEET - PMS PAVEMENTS

County, Route & Section	Length, Miles	Classification	Profile Index (0.2")
VI-Fre-4-A	2.1	Smooth	2.5
I-Hum-1-H	3.2	Smooth	3.5
II-Teh-3-A	0.9	Smooth	7.0
V-Sol-2-B	2±	Smooth	10.4
III-Sha-3-B	2.5	Fair to Smooth	18.0
I-Men-1-C	0.5	Rough in spots	19
VI-Fre-4-B	2.2	Fair	21
I-Men-1-D	2.1	Rough in spots	24
XI-S.D-2-G	1.5	Fair	29
III-Gle-7-B	1.1	Rough (AC)	40
IV-S.M-68-Bm.	1.6	Rough	49

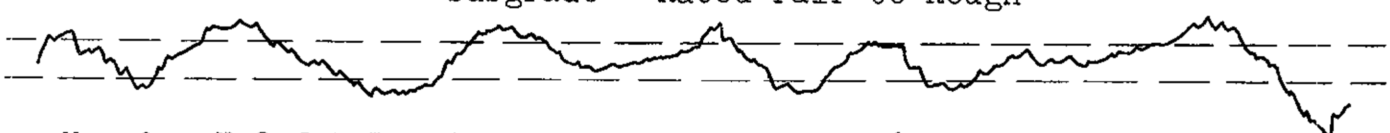
TYPICAL PROFILES OF
PORTLAND CEMENT CONCRETE PAVEMENTS

Figure 1

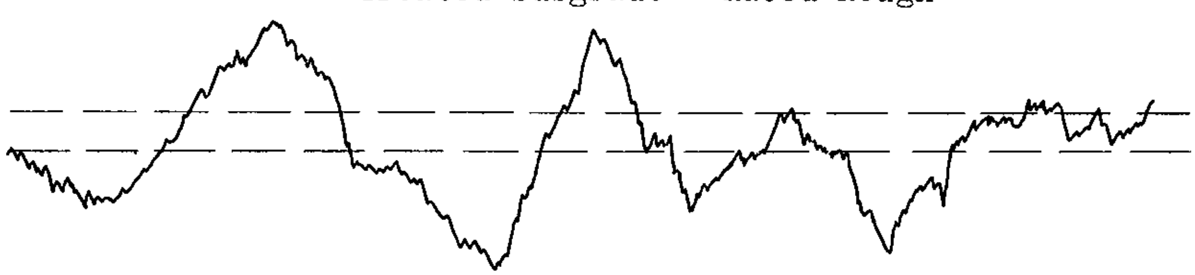
No. 1 X-S.J-4-A Constructed in 1955, Portland Cement Concrete over Cement Treated Subgrade - Rated Smooth*
PrI = 2.1



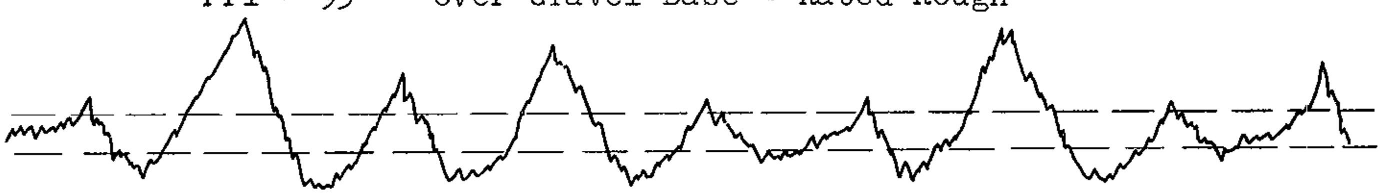
No. 2 X-S.J-4-B,E Constructed in 1956, 24' Monolithic Pavement Portland Cement Concrete over Cement Treated Subgrade - Rated Fair to Rough
PrI = 31



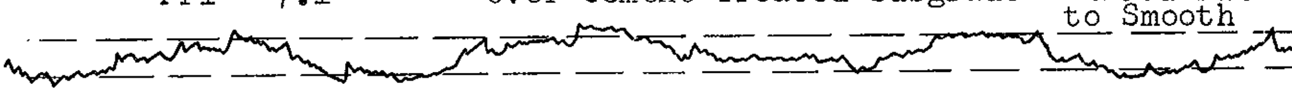
No. 3 X-S.J-4-B Constructed August, 1956, 24' Monolithic Pavement. Portland Cement Concrete over Cement Treated Subgrade - Rated Rough
PrI = 69



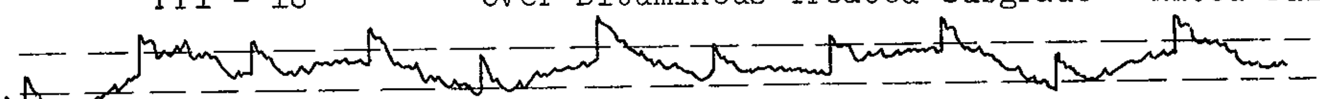
No. 4 III-Col-7-B Constructed in 1931, Portland Cement Concrete over Gravel Base - Rated Rough
PrI = 93



No. 5 IV-Ala-69-Snl,C Constructed 1951, Portland Cement Concrete over Cement Treated Subgrade - Rated Fair to Smooth
PrI = 7.1



No. 6 IV-Ala-69-Oak Constructed 1949, Portland Cement Concrete over Bituminous Treated Subgrade - Rated Fair
PrI = 18



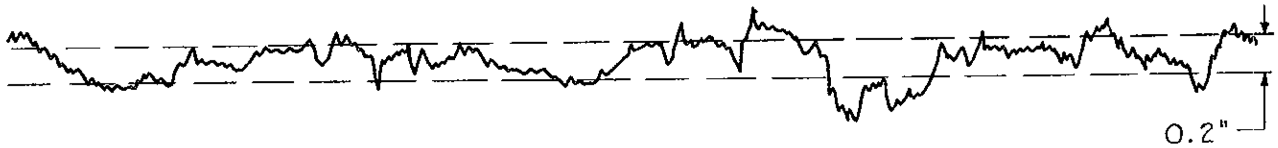
PrI = Profile Index (0.2") = inches per mile in excess of 0.2"
Horizontal Scale: 1" = 25' Vertical Scale: 1" = 1"

*These ratings are drivers impression while riding in a light car at approximately 50 miles per hour.

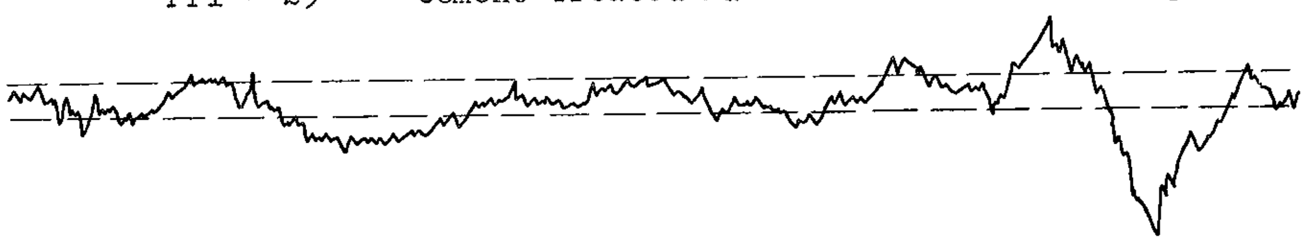
TYPICAL PROFILES OF
BITUMINOUS TYPE PAVEMENTS

Figure 2

No. 1 III-Gle-7-B Constructed in 1937, $5\frac{1}{2}$" Asphaltic Concrete over
PrI = 40 6" Imported Base over 4" old Portland Cement Conc.
Rated Rough*



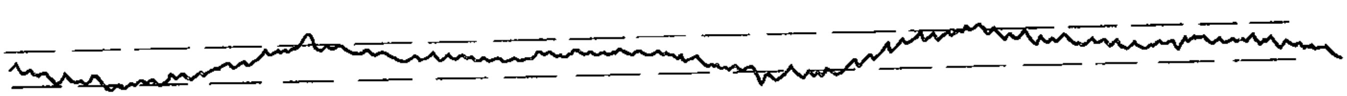
No. 2 XI-S.D-2-G Constructed 1951, Plant-mix surfacing over
PrI = 29 Cement Treated Base - Rated Fair to Rough



No. 3 I-Men-1-D Constructed 1949, Plant-mix surfacing over
PrI = 24 Cement Treated Base - Rated Rough

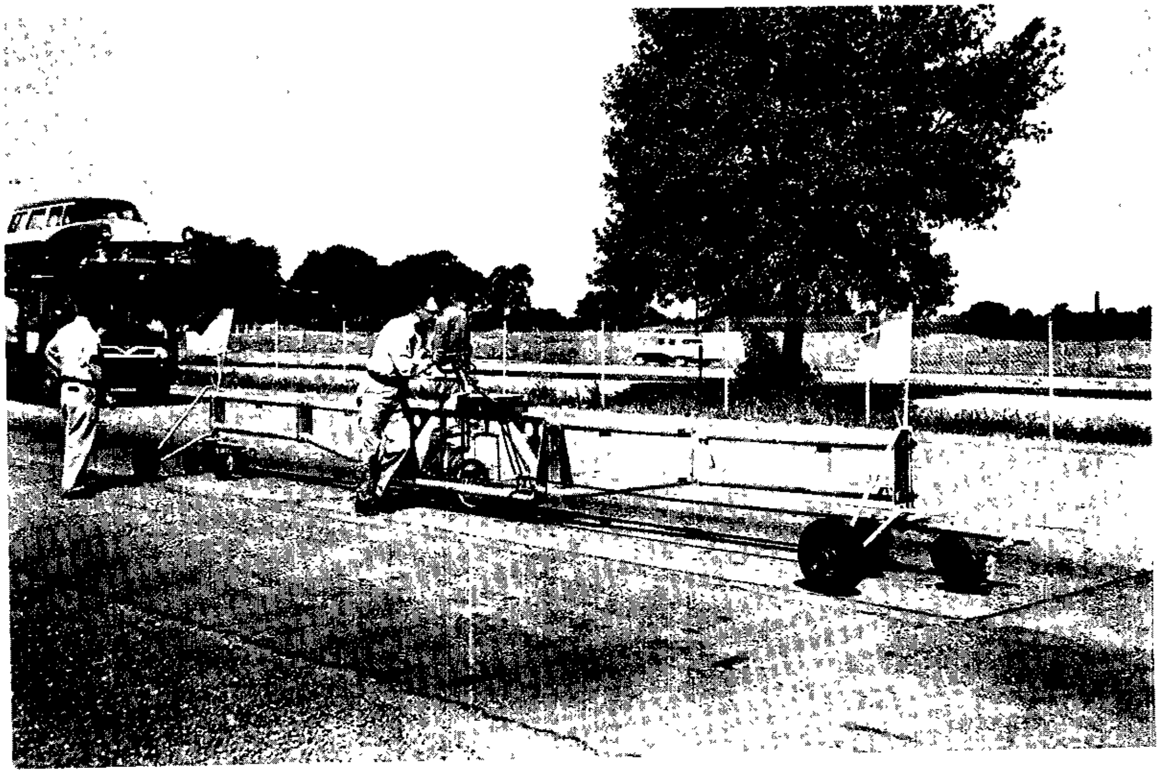
No. 4 V-SLO-2-B Constructed 1953, Plant-mix surfacing over
PrI = 10.4 Cement Treated Base - Rated Smooth

No. 5 VI-Fre-4-A Constructed 1953, 2" Plant-mix surfacing over
PrI = 2.5 5" Asphaltic Concrete over 4" Portland Cement
Concrete - Rated Smooth

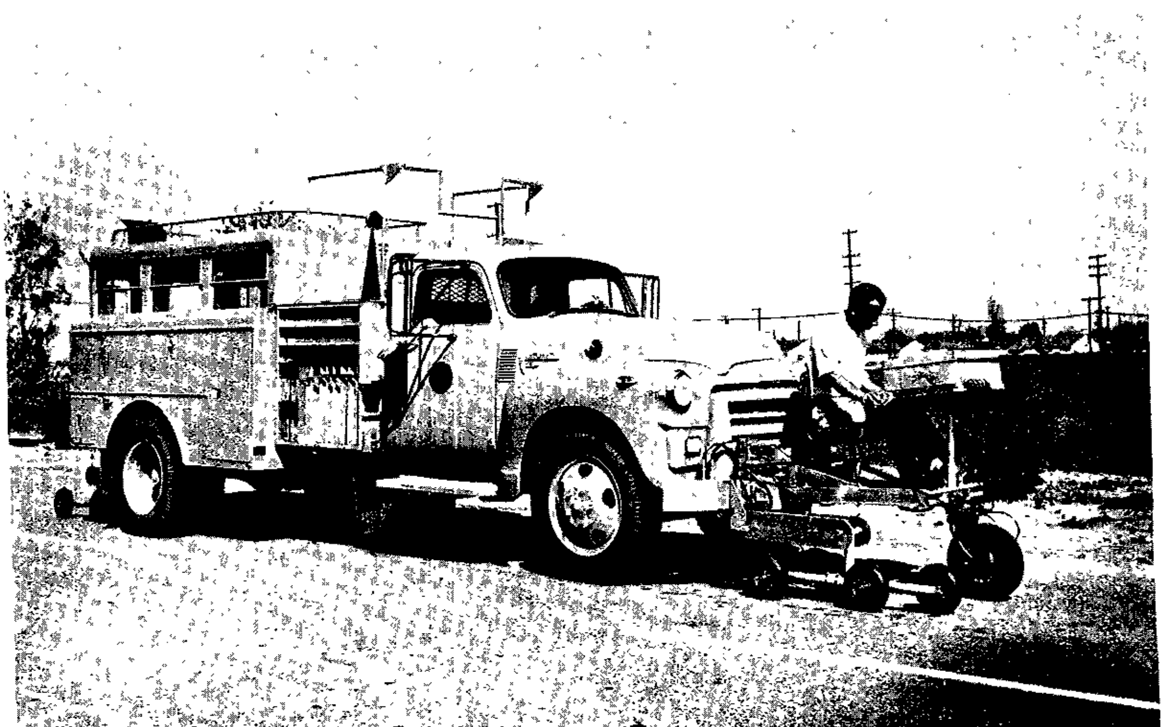


PrI = Profile Index (0.2") = inches per mile in excess of 0.2"
Horizontal Scale: 1" = 25' Vertical Scale: 1" = 1"

*These ratings are drivers impression while riding in a light car at approximately 50 miles per hour.



Hand-Pushed Profilograph



Truck-Mounted Profilograph